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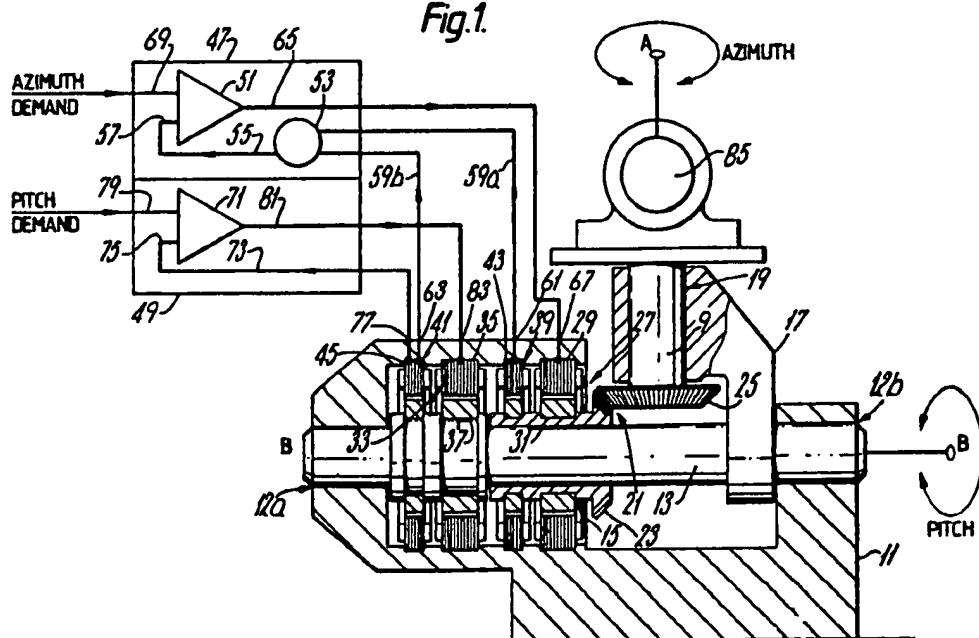
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#### (54) System for producing angular displacement

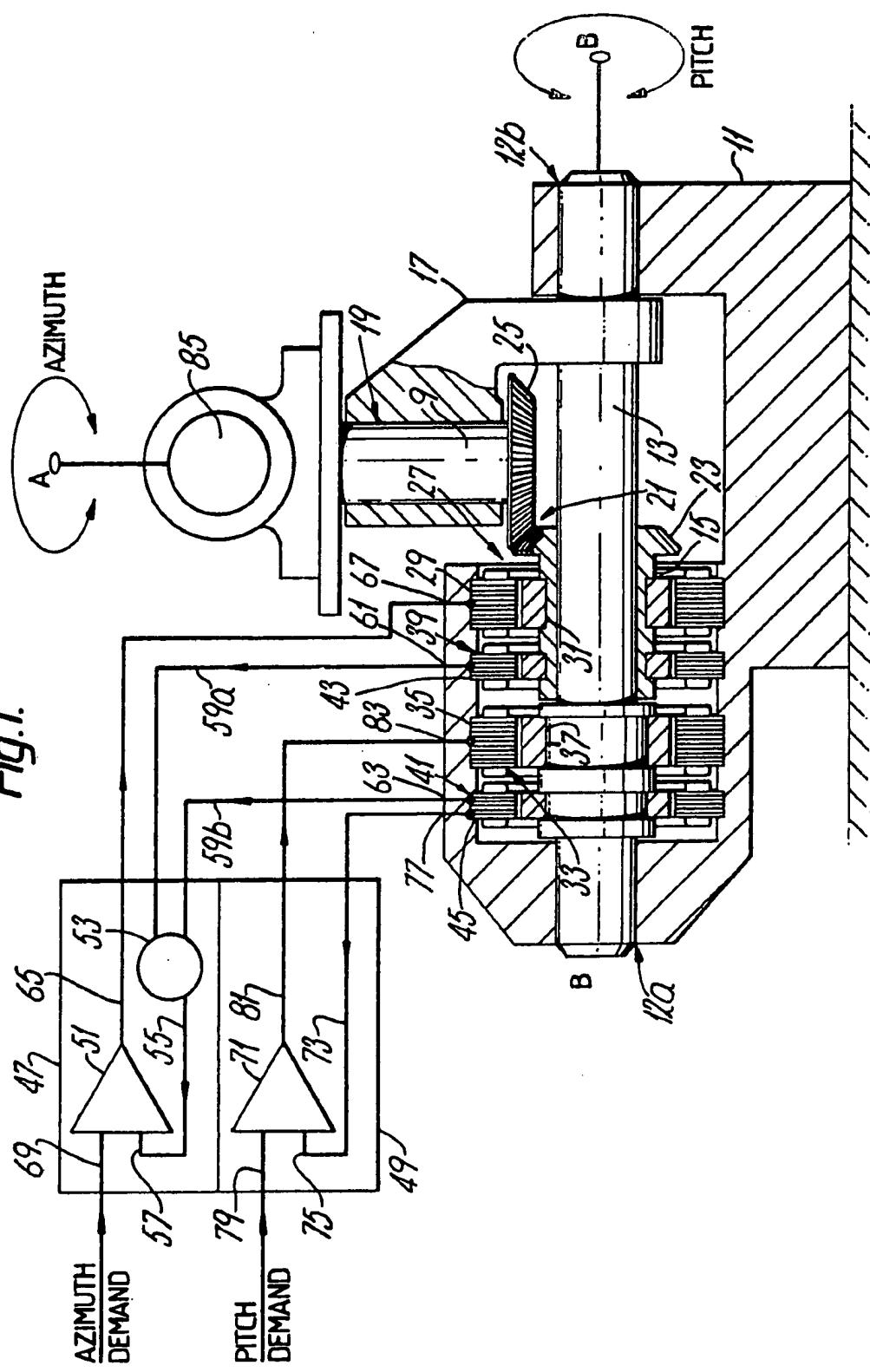
(57) A system for producing angular displacement about a first axis (A) of an output member (9) which is also angularly displaceable about a second axis (B) transverse to the first axis comprising a drive motor (27) having a stator (29) on a frame (11) and a rotor (31) on a drive transmission member (15) mounted for rotation about the second axis (B) and coupled to the output member (9) to alter its angular position about the first axis (A). A first pick up means (41) senses the angular position of the output member (9) about the second axis (B) with respect to the frame (11) and a second pick up means (39) senses the angular position of the transmission member (15) about the second axis (B) with respect to the frame (11), and a servo loop (47) responsive to the pick up outputs and an angular displacement demand signal drives the motor (27). One particular application of the system is for helicopter rotor blade pitch control, the first axis then being the rotor blade pitch axis and the second axis the rotor rotation axis.

Fig.1.



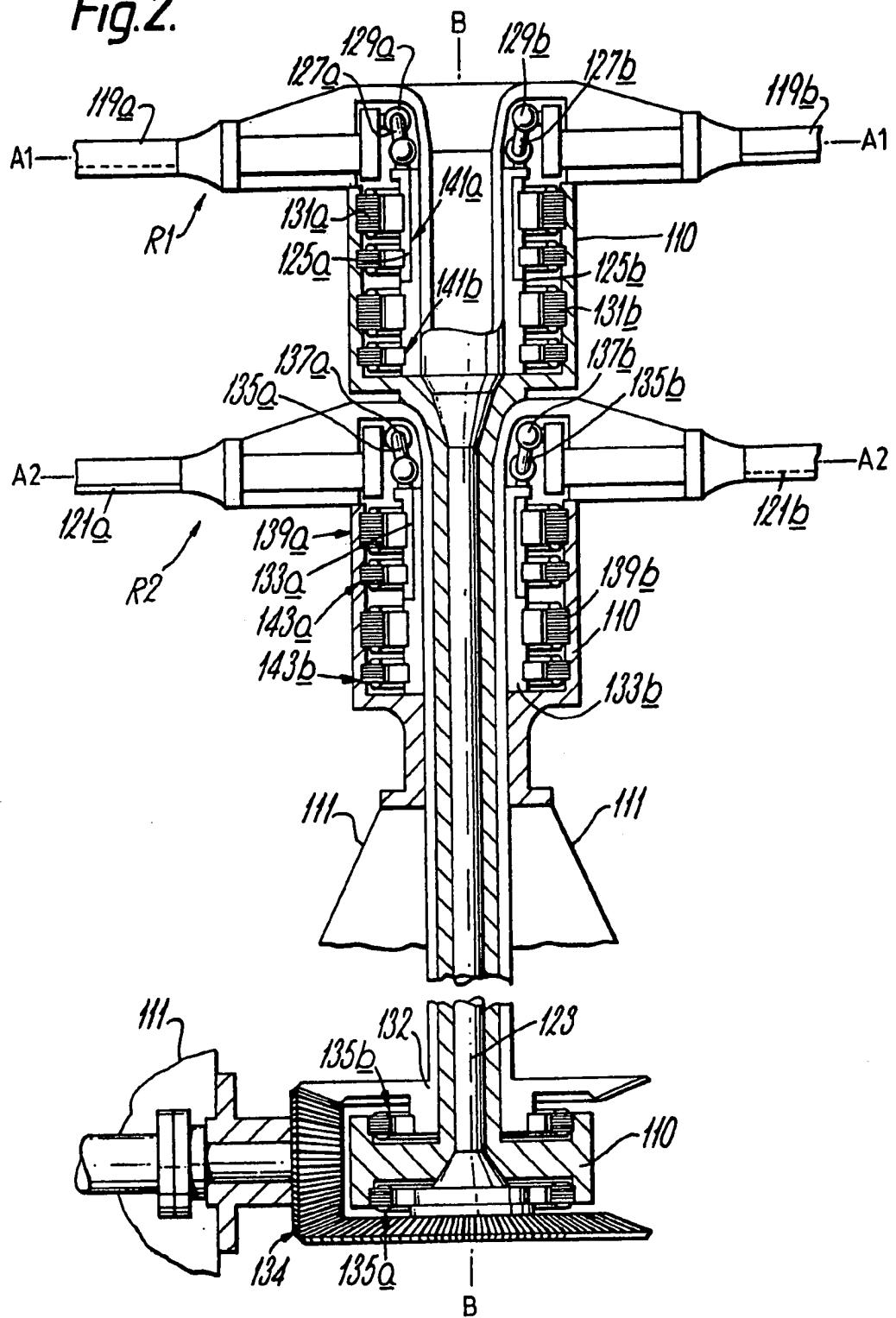
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Fig.1.



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Fig. 2.



## SPECIFICATION

## Systems for producing angular displacement

5 This invention relates to systems for producing angular displacement.

More particularly, the invention relates to systems for producing angular displacement about a first axis of an output member which is also angularly displaceable about a second axis transverse to said first axis.

10 One application of such a system is in the control of the pitch of the rotor blade of a helicopter. In such an application, the output member is the rotor blade which is angularly displaced about a first axis to vary blade pitch, and which is also angularly displaced about a second axis, i.e. the axis of rotation of

15 the helicopter rotor drive shaft.

Commonly, helicopter rotor blades are collectively and cyclically controlled in pitch by means of a swash plate arrangement and a system of linkages each linkage extending

20 between a swash plate and a crank portion, or control horn, of an associated one of the rotor blades. The swash plate arrangement encompasses the drive shaft, i.e. the output shaft of the helicopter engine, and the tilt of the

25 swash plate referred to above in response to pitch demands is transmitted by way of the linkages to the respective rotors.

The disadvantages of such arrangements are firstly that they are mechanically complicated and secondly that they are limited to the use of sinusoidal rotor pitch input demands.

30 It has been proposed in GB-A-2090214 to employ individual electric motors at the rotor blade roots and to energize these motors in accordance with rotor pitch input demands fed to the motors from the rotor hub by way of slip rings. However, the integrity of such an arrangement is highly suspect since the reliability of slip rings is not sufficient to warrant

35 their utilization in such a critical aspect of helicopter design as the operation of the rotor.

It is an object of the present invention to provide a system for producing angular displacement about a first axis of an output

40 member which is also angularly displaceable about a second axis transverse to said first axis whereby these disadvantages are overcome.

45 According to the invention a system for producing an angular displacement about a first axis of an output member which is also angularly displaceable about a second axis transverse to said first axis comprises: a frame incorporating first bearing means defining said

50 second axis; a first drive transmission member which is angularly displaceable in the said first bearing means; a second drive transmission member which is angularly displaceable about said second axis; a lateral projection

55 rigid with said first drive transmission member

and incorporating second bearing means defining said first axis and within which said output member is angularly displaceable; angular displacement transmission means coupling said second drive transmission member and said output member and operable to produce angular displacement of said output member about said first axis in response to angular displacements of said second drive transmission member; a motor having a stator which is fixed with respect to said frame and a rotor which is drivingly coupled to said second drive transmission member; a first pick-off for sensing angular displacement of the said first drive transmission member with respect to a datum defined in said frame; a second pick-off for sensing angular displacement of the said second drive transmission member with respect to said datum; and a servo having its output arranged to supply power to the stator of said motor and operable to develop power dependent upon a servo input demand for rotation of said output member about said first axis and the outputs of the said first and second pick-offs; said pick-offs, the servo and said motor constituting a closed loop error actuated position feedback system.

Said second drive transmission member is suitably mounted coaxially around said first drive transmission member.

The system may further include a second motor having a stator which is fixed with respect to said frame and a rotor which is drivingly coupled to said first drive transmission member, the stator of said second motor being supplied with power in dependence upon a demand for rotation of said output member about said second axis. In such an arrangement said power supplied to the stator of said second motor may be derived from a second servo operable to develop power dependent upon a servo input demand for rotation of said output member about said second axis and the output of said first pick-off, said first pick-off, the second servo and said second motor constituting a closed loop error actuated position feedback system.

In one particular embodiment, the invention provides a helicopter rotor blade pitch control system comprising: a frame structure incorporating first bearing means defining the axis of revolution of the helicopter rotor drive shaft; a drive transmission member sharing a common rotary axis with the helicopter rotor drive shaft; a lateral projection rigid with the helicopter rotor drive shaft and incorporating helicopter rotor blade pitch axis bearing means within which the helicopter rotor blade is angularly displaceable; a motor associated with said transmission member, the stator of said motor being fixed with respect to said frame structure and the rotor of said motor being fixed with respect to said transmission

100 member; a drive shaft pick-off for sensing the

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angular position of the drive shaft with respect to a datum fixed in the frame structure; an angular displacement transmission means coupling the rotor blade to said drive transmission member; a drive transmission member pick-off for sensing the angular displacement of said drive transmission member with respect to the said datum; and a servo having its output arranged to supply power to the input of said motor and operable to develop power dependent upon a servo input demand for rotation of said rotor blade about said rotor blade pitch axis and the output of said drive shaft pick-off and said drive transmission member pick-off, 10 the drive shaft pickoff, the motor and the transmission member pick-off constituting an error actuated closed loop position feedback control system for controlling the pitch of the rotor blade in accordance with a pitch demand to the servo.

With such an arrangement the complexities of mechanical helicopter rotor pitch control arrangements may be avoided; and at the same time rotor pitch demands of substantially any desired form may be introduced. Optimization of rotor pitch demands becomes available as a consequence.

Said drive transmission member is preferably mounted coaxially around said helicopter 30 rotor drive shaft.

The invention further provides a helicopter rotor blade pitch control system having a helicopter rotor blade pitch control system according to the invention for each rotor 35 blade, each said system for a blade including a separate said drive transmission member, said lateral projection incorporating helicopter rotor blade pitch axis bearing means; said motor; said angular displacement transmission means, said drive transmission member pick-off and said servo.

In a system according to the invention the or each motor is suitably an electric motor e.g. a brushless electric motor, or a hydraulic 45 motor.

It will be appreciated that in a system according to the invention, since the or each motor has its stator fixed to the frame, power can easily be supplied to the motor or motors, 50 i.e. without the need for slip rings where the motors are electric, or the need for rotary fluid couplings where the motors are hydraulic.

In a system according to the invention the or each angular displacement transmission 55 means may comprise mating bevel gears. Conveniently, however, and particularly in relation to helicopter rotor blade pitch control systems, the or each such transmission means may comprise a pivotal linkage.

60 The pick-offs suitably comprise brushless electric pick-offs.

Two systems in accordance with the invention will now be described by way of example with reference to the accompanying drawings 65 in which:

Figure 1 shows, schematically, and in part longitudinal section, elements of a system for controlling a camera in pitch and azimuth; and

70 Figure 2 is a schematic sectional view of elements of a twin rotor helicopter rotor blade pitch control system.

Referring to Figure 1, the camera pitch and azimuth control system serves to produce an

75 angular displacement about a first axis A in an output member 9 which is angularly displaceable, also, about a second axis B orthogonal to the said first axis.

The system has a frame 11 incorporating 80 first bearing means 12a, 12b defining the axis B. The inner one 13 of two coaxial drive shafts 13, 15, respectively, is supported by the frame 11 in the bearings 12a, 12b. A laterally projecting arm 17, which is integral

85 with the drive shaft 13, incorporates second bearing means 19 defining the axis A. The output member 9 is angularly displaceable within the said second bearing means 19.

Between the outer one 15 of the two coaxial drive shafts 13, 15 and the output member 9 there are provided angular displacement transmission means 21, specifically, mating bevel gears 23, 25. The gear 23 is integral 95 with the drive shaft 15, the gear 25 with the output member 9.

A first electric motor 27 has its stator 29 fixed with respect to the apparatus frame 11, and its rotor 31 drivingly coupled to the outer coaxial drive shaft 15.

100 A second electric motor 33 has its stator 35 fixed with respect to the frame 11, and its rotor 37 drivingly coupled to the inner coaxial drive shaft 13.

There is a first electric pick-off 41 for sensing angular displacement of the inner drive shaft 13 with respect to a datum (not shown) fixed in the frame 11; and a second electric pick-off 39 senses angular displacement of the outer shaft 15 with respect to the said 110 datum. Each of the pick-offs 39, 41 has its stator 43, 45, respectively, fixed in the frame 11 and its angularly displaceable part fixed to the drive shaft, 13 or 15, as the case may be.

The final essential elements of the system 115 are servos 47 and 49.

The servo 47 comprises an operational amplifier 51 and a signal summing circuit 53. The summing circuit 53 has its output 55 connected to an input 57 to the amplifier 51 and has inputs, 59a, 59b, connected to the outputs 61, 63, respectively, of the pick-offs 39, 41. The output 65 of the amplifier 51 is connected to the input 67 to the motor 27. The amplifier 51 has an input 89 to which 125 input demand signals for demanding rotation about the axis A, the azimuth axis, are applied.

The servo 49 comprises an operational amplifier 71 alone, there is no associated summing circuit since the only feedback path is the 130

connection 73 between input 75 of the amplifier 71 and output 77 of pick-off 41. The amplifier 71 has an input 79 to receive pitch demand signals i.e. demands for rotation about axis B; and its output 81 is connected to the input 83 of the motor 33.

The motors and pick-offs are all brushless devices involving no use of slip rings to supply power to the motor or derive output from the pick-offs. The electric motors, in particular, are preferably rare earth brushless slab motors.

A camera, represented in Figure 1 by the circular portion 85 of the output member 9, is angularly displaceable in pitch and azimuth in accordance with the inputs to the amplifiers 71, 51, respectively.

Consider a demand to the azimuth channel alone, the pitch of the camera 85 to remain unchanged throughout. In response to the azimuth demand the resulting input to the stator 29 of the motor 27 produces a corresponding angular displacement in the rotor 31. Rotation, in the outer drive shaft 15 to which the rotor 31 is coupled, is transmitted to the output member 9 and, hence, the camera 85 by way of the bevel gears 23 and 25. It will be appreciated that there is no cross-coupling from the azimuth axis A to the pitch axis B; accordingly, no pitch channel feedback signal is supplied to the summing point 53, the only signal there appearing being that developed at the output 61 of the pick-off 39. The latter signal is effective, of course, to back-off the azimuth demand signal when the angular displacement in azimuth of the camera 85 corresponds to the azimuth demand input at the amplifier 51.

Consider, next, a demand to the pitch channel alone. Such a demand produces a corresponding input to the stator 35 of the motor 33 which produces an angular displacement in the rotor 37. Consequent rotation in the drive shaft 13 is transmitted to the output member 9 by way of the laterally projecting arm 17. Rotation of the arm 17 about the axis B gives rise to a change in pitch angle in the camera 85. The signal developed at the output 77 of the pitch pick-up 41 backs off the pitch demand signal when the angular displacement in pitch of the camera 85 corresponds to the pitch demand input at the amplifier 71. In this case, however, there is a cross-coupling between axes since the meshing of the bevel gears 23, 25 produces an incipient change in azimuth in the output member 9 and, hence, the camera 85, as a result of the propensity of the gear 25 to roll on the gear 23. The signal developed at the output 63 of the pitch pick-off 41 is applied to the summing point 53 which, in response, develops an output. The amplifier 51 responds to the summing point output to produce an output serving to energise the azimuth drive motor 27. The resulting rotation of

the azimuth drive shaft 15, through the meshing gears, 23 and 25, produces an azimuth displacement in the output member 9 and hence the camera 85. This continues until the signal on the output 61 of azimuth pick-up 39 backs off the signal applied to summing point 53 by the pitch pick-off 41 on output 63 and the amplifier output is at a null and the azimuth motor is no longer active. By this means the cross-coupling from the pitch to the azimuth axis is compensated.

Referring now to Figure 2, the helicopter rotor pitch control system has dual rotors  $R_1$  and  $R_2$  mounted one above the other. As may be seen each rotor  $R_1, R_2$  has two diametrically opposed blades, 119a, 119b; 121a, 121b. There are three coaxial drive shafts 123, 125a, 125b associated with each rotor. For the upper rotor  $R_1$ , the innermost one 123 of these drive shafts, which transmits the rotor drive extends to the upper rotor  $R_1$  centrally through the lower rotor  $R_2$ . The other two coaxial drive shafts 125a, 125b are associated with the rotor blades 119a, 119b respectively, fit coaxially around the shaft 123, and are coupled the one 125a to the rotor blade 119a, the other 125b to the rotor blade 119b, by means of pivotal linkages 127a, 127b, one end 129a, 129b of each of the linkages 127a, 127b being connected to the associated rotor blade 119a, 119b, respectively, at an off-axis position. Angular displacement of the drive shafts 125a, 125b effects a pitch change in, i.e. a rotation about the common longitudinal axis of, the two rotor blades 119a, 119b. Angular displacement of the drive shafts 125a, 125b is produced by appropriate energization of brushless electric motors 131a, 131b, respectively whose stators are fixed to parts 110 which are fixed to helicopter airframe 111, i.e. non-rotary parts, such parts being shown shaded in Figure 2.

Associated with the rotor  $R_2$  there are, encompassing the shaft 123, three coaxial shafts 132, 133a and 133b. The innermost shaft 132 transmits the rotor drive and is surrounded by coaxial shafts 133a and 133b which are respectively coupled to the opposed blades 121a, 121b of the rotor  $R_2$  by pivotal linkages 135a, 135b having their ends 137a, 137b connected to the blades at off-axis positions. Motors 139a, 139b when energized produce angular displacement in the rotor blades 121a, 121b by their displacement of the coaxial shafts 133a, 133b, respectively.

The shafts 123 and 132 are, of course, driven from a helicopter lift engine (not shown). A double crown and pinion gear 134 transmits drive from the engine to the shafts 123, 132 and hence to the rotors  $R_1, R_2$ . Associated with the shafts 125a, 125b; 133a, 133b there are corresponding pick-offs 141a, 141b; 143a, 143b. Associated with the shafts 123, 132 there are pick-offs 135a and 135b which therefore provide measure-

ment of angular displacement of the pick-offs 141a, 141b and the pick-offs 143a, 143b respectively. The stators of all the pick-offs mentioned are, as shown, fixed in the air-frame.

The control of angular blade pitch movement in the helicopter rotors R<sub>1</sub>, R<sub>2</sub> is by means of servos (not shown). With the arrangement of Figure 2 there exists cross coupling between the rotor blade pitch axes A<sub>1</sub>—A<sub>1</sub>, and A<sub>2</sub>—A<sub>2</sub> and the helicopter rotor rotation axis B—B. The rotor pitch servos are thus essentially similar to the azimuth servo 47 depicted in Figure 1. Hence cross coupling between the rotor rotation axis B—B and the rotor pitch axes A<sub>1</sub>—A<sub>1</sub>, and A<sub>2</sub>—A<sub>2</sub> is compensated by compensating inputs from the rotor rotation pick-offs 135a, 135b (cyclically recurring in this case) to the rotor pitch servos. Rotor blade pitch demand signals, are, of course, also applied to the rotor blade pitch demand servos, superimposed upon the said cyclically recurring inputs.

It will be understood that in the arrangement of Figure 2 there is no servo corresponding to the pitch servo 49 of Figure 1, the rotors R<sub>1</sub> and R<sub>2</sub> being driven directly from the helicopter lift engine.

Whilst linkages 129a, 129b; 135a, 135b are depicted in Figure 2 coupling drive shafts 125a, 125b; 133a, 133b to the rotors R<sub>1</sub>, R<sub>2</sub>, bevel gears similar to those shown in Figure 1 could be employed instead.

Whilst electric motors are used in the system of Figure 1 as the drive for both angular displacements, and in the arrangement of Figure 2, electric motors are used for the drive for one angular displacement (blade pitch) and an internal combustion engine (the helicopter lift engine) as the drive for the other angular displacement (rotor rotation), it will be understood that the present invention does not require the use of any particular form of drive motors. The utility of the invention resides in the fact that the drive motors are all mounted so that their stators parts do not rotate as the output member is angularly displaced, thus simplifying the supply of power to the motors. Thus virtually any kind of motor may be used in a system according to the invention although, in practice, only motors capable of precise control will normally be used for at least one of the angular displacements. Thus hydraulic motors might conveniently be used instead of the electric motors in the systems described by way of example.

#### CLAIMS

60 1. A system for producing an angular displacement about a first axis of an output member which is also angularly displaceable about a second axis transverse to said first axis comprising: a frame incorporating first bearing means defining said second axis; a

first drive transmission member which is angularly displaceable in the said first bearing means; a second drive transmission member which is angularly displaceable about said

70 second axis; a lateral projection rigid with said first drive transmission member and incorporating second bearing means defining said first axis and within which said output member is angularly displaceable; angular displacement transmission means coupling said second drive transmission member and said output member to produce angular displacement of said output member about said first axis in response to angular displacements of said

75 second drive transmission member; a motor having a stator which is fixed with respect to said frame and a rotor which is drivingly coupled to said second drive transmission member; a first pick-off for sensing angular displacement of the said first drive transmission member with respect to a datum defined in said frame; a second pick-off for sensing angular displacement of the said second drive transmission member with respect to said datum; and a servo having its output arranged to supply power to the stator of said motor and operable to develop power dependent upon a servo input demand for rotation of said output member about said first axis and

90 95 the outputs of the said first and second pick-offs; said pick-offs, the servo and said motor constituting a closed loop error actuated position feedback system.

2. A system according to Claim 1 wherein said second drive transmission member is mounted coaxially around said first drive transmission member.

3. A system according to Claim 1 or Claim 2 further including a second motor having a 105 stator which is fixed with respect to said frame and a rotor which is drivingly coupled to said first drive transmission member, the stator of said second motor being supplied with power in dependence upon a demand for 110 rotation of said output member about said second axis.

4. A system according to Claim 3 wherein said power supplied to the stator of said second motor is derived from a second servo 115 operable to develop power dependent upon a servo input demand for rotation of said output member about said second axis and the output of said first pick-off, said first pick-off, the second servo and said second motor constituting a closed loop error actuated position feedback system.

5. A helicopter rotor blade pitch control system comprising: a frame structure incorporating first bearing means defining the axis of 125 revolution of the helicopter rotor drive shaft; a drive transmission member sharing a common rotary axis with the helicopter rotor drive shaft; a lateral projection rigid with the helicopter rotor drive shaft and incorporating heli-copter rotor blade pitch axis bearing means

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within which the helicopter rotor blade is angularly displaceable; a motor associated with said transmission member, the stator of said motor being fixed with respect to said frame structure and the rotor of said motor being fixed with respect to said transmission member; a drive shaft pick-off for sensing the angular position of the drive shaft with respect to a datum fixed in the frame structure; an angular displacement transmission means coupling the rotor blade to said drive transmission member; a drive transmission member pick-off for sensing the angular displacement of said drive transmission member with respect to the said datum; and a servo having its output arranged to supply power to the input of said motor and operable to develop power dependent upon a servo input demand for rotation of said rotor blade about said rotor blade pitch axis and the output of said drive shaft pick-off and said drive transmission member pick-off, the drive shaft pick-off, the motor and the transmission member pick-off constituting an error actuated closed loop position feedback control system for controlling the pitch of the rotor blade in accordance with a pitch demand to the servo.

6. A system according to Claim 5 wherein said drive transmission member is mounted coaxially around said helicopter rotor drive shaft.

7. A helicopter rotor blade pitch control system having a system according to Claim 5 or Claim 6 for each rotor blade, each said system for a blade including a separate said drive transmission member, said lateral projection incorporating helicopter rotor blade pitch axis bearing means; said motor; said angular displacement transmission means, said drive transmission member pick-off and said servo.

8. A system according to Claim 7 including two rotors mounted one above the other, the rotor drive shaft for the upper rotor extending through the drive shaft for the lower rotor.

9. A system according to any one of the preceding claims wherein the or each motor is an electric motor.

10. A system according to Claim 9 wherein the or each motor is a brushless electric motor.

11. A system according to any one of Claims 1 to 8 wherein the or each motor is a hydraulic motor.

12. A system according to any one of the preceding claims wherein the or each angular displacement transmission means comprises mating bevel gears.

13. A system according to any one of Claims 1 to 11 wherein the or each said angular displacement transmission means comprises a pivotal linkage.

14. A system according to any one of the preceding claims wherein said pick-offs are brushless electrical pick-offs.

15. A system for producing an angular

displacement about a first axis of an output member which is also angularly displaceable about a second axis transverse to said first axis substantially as hereinbefore described with reference to Figure 1.

16. A helicopter rotor blade pitch control system substantially as hereinbefore described with reference to Figure 2.

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## INTERNATIONAL SEARCH REPORT

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According to International Patent Classification (IPC) or to both national classification and IPC

## B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)  
IPC 7 A63H

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

EPO-Internal, WPI Data, PAJ

## C. DOCUMENTS CONSIDERED TO BE RELEVANT

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A	DE 299 19 462 U (PUETZ ENGELBERT) 17 February 2000 (2000-02-17) the whole document	1

 Further documents are listed in the continuation of box C. Patent family members are listed in annex.

## \* Special categories of cited documents :

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